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Probing magnetic fields with GALFACTS

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Abstract. GALFACTS is a large-area spectro-polarimetric survey on the Arecibo Radio telescope. It uses the seven-beam focal plane feed array receiver system (ALFA) to carry out an imaging survey project of the 12,700 square degrees of sky visible from Arecibo at 1.4 GHz with 8192 spectral channels over a bandwidth of 300 MHz sampled at 1 millisecond. The aggregate data rate is 875 MB/s. GALFACTS observations will create full-Stokes image cubes at an angular resolution of 3.5' with a band-averaged sensitivity of 90 μ Jy, allowing sensitive imaging of polarized radiation and Faraday Rotation Measure from both diffuse emission and extragalactic sources. GALFACTS is a scientific pathfinder to the SKA in the area of cosmic magnetism. Key to magnetism science with the SKA is the technique of RM synthesis. The technique of RM synthesis is introduced and we discuss practical aspects of RM synthesis including efficient computational techniques and detection thresholds in the resulting Faraday spectrum. We illustrate the use of the technique by presenting the current development of the RM synthesis pipeline for GALFACTS and present early results.

1. Introduction

Linear polarization of radio sources contains information on magnetic fields in these sources, and Faraday rotation of the plane of polarization provides information on the direction and magnitude of the magnetic field along the line of sight. As such, observations of linear polarization of radio sources provide the most widely applicable probe of cosmic magnetic fields on scales from galaxies to clusters of galaxies. Finding polarized sources in survey images and fitting their parameters forms the basis of this analysis.

The Galactic ALFA Continuum Survey Consortium is using the Arecibo telescope and ALFA to carry out a sensitive, high resolution, spectro-polarimetric survey of the region of the sky visible with the Arecibo telescope (Taylor & Salter 2010). A key observational objective of the GALFACTS is to image the polarized emission from both discrete objects and the diffuse interstellar medium of our Galaxy and to derive polarization properties, including Faraday Rotation Measures (RMs) for a vast population of extragalactic sources. A detailed discussion on the GALFACTS project can be found in Taylor & Salter (2010).

The objective of GALFACTS is to produce high sensitivity Stokes I , Q , U and V multi-frequency images of the polarized emission over the full range of Galactic lati-

tudes from the mid-plane to the pole. GALFACTS has a bandwidth of 300 MHz over 1225–1525 MHz, allowing imaging of Faraday rotation measures. The 1σ survey sensitivity over the full band is $\sim 80 \mu\text{Jy}$ per Stokes parameter ($\Delta T_{rms} \sim 0.8 \text{ mK}$) with a $3.4'$ resolution (maximum baseline 220m); The total sky coverage of the full survey is 12,734 degrees which requires a total observing time 1600 hours. Since the GALFACTS survey produces terabyte sized data sets, the data processing pipeline raises considerable challenges. Here we limit our discussion to the RM synthesis methods applied to the processed image data, a detailed description of the GALFACTS pipeline is given in Guram et al. (2011).

2. Rotation Measure Synthesis

Polarimetric radio observations enable the study of synchrotron emission radiated by relativistic electrons as they are accelerated by magnetic fields. Multifrequency observations allow RM Synthesis (Burn 1966) to solve for the unknown Faraday depth, polarized intensity, and polarization angle simultaneously. The source is typically identified by the maximum value in the Faraday spectrum. Following Brentjens & de Bruyn (2005) the Faraday depth ϕ is defined as

$$\phi(\vec{r}) = 0.81 \int_0^x \vec{B}_{\parallel} n_e \cdot d\vec{r} \text{ rad m}^{-2}, \quad (1)$$

where \vec{B}_{\parallel} is the line of sight magnetic field component, n_e is the thermal electron density, $d\vec{r}$ is an infinitesimal path length, with the integral taken from the observer to the point x .

The complex polarized intensity $\mathcal{P}(\lambda^2) = Q + iU$ is the Fourier transform of the Faraday dispersion function $F(\phi)$,

$$P(\lambda^2) = \int_{-\infty}^{\infty} F(\phi) e^{2i\phi\lambda^2} d\phi. \quad (2)$$

The Faraday rotation measure RM is defined as the slope of a polarization angle Ψ versus λ^2 :

$$RM(\lambda) = \frac{d\Psi}{d(\lambda^2)} \quad (3)$$

where

$$\Psi = \frac{1}{2} \tan^{-1} \frac{U}{Q}. \quad (4)$$

Once a polarized source has been detected, the observed polarized intensity $p = \sqrt{Q^2 + U^2}$ must be corrected for polarization bias. Since p is a positive-definite quantity, the noise in Stokes Q and U results in a positive value for p even if no signal is present. The statistics of p with a signal p_0 and noise σ_{QU} is given by the Rice distribution (Rice 1945). This matter is complicated by the uncertainty in the Faraday depth of the source. This introduces a stronger bias in the polarized intensity than the well known polarization bias but can be corrected for (George et al. 2011).

3. Application to GALFACTS

The first GALFACTS dataset (N1 region) is a cube of 5314 by 1074 pixels with 4096 spectral channels. The large number of pixels means that to do effective RM synthesis is computationally expensive. To solve this RM synthesis can be run in parallel on each pixel in the image plane with the results being combined to form one Faraday depth cube. This is currently not part of the main GALFACTS pipeline (Guram et al. 2011) but will be integrated as an application on <http://www.cyberska.org> (Kiddle et al. 2011). Another way to approach the RM synthesis is to average the Stokes Q and U data in frequency, correctly selecting the window to average so that no information is lost in the result Faraday depth cube. For the N1 region RM synthesis was completed over a range of -1200 to 1200 rad.m^{-2} with an averaging of 0.4 MHz in the Q and U . To visualize the Faraday depth cube is difficult with such a large dataset and to overcome this limitation a moment map was created. A preliminary RM map from the N1 GALFACTS observations run is shown in Figure 1 with a typical compact source Faraday spectrum given in Figure 2. Residual imaging artefacts dominate the compact sources but lots of structure can be seen in the diffuse emission.

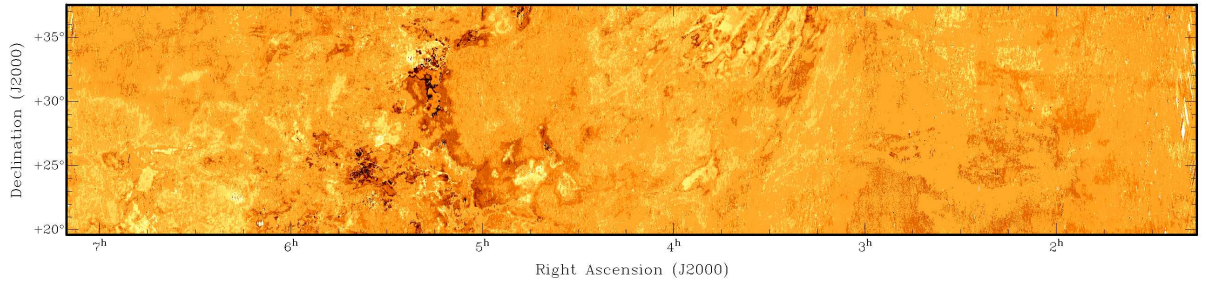


Figure 1: A moment map of a subset of the N1 region showing structure in the Faraday spectrum

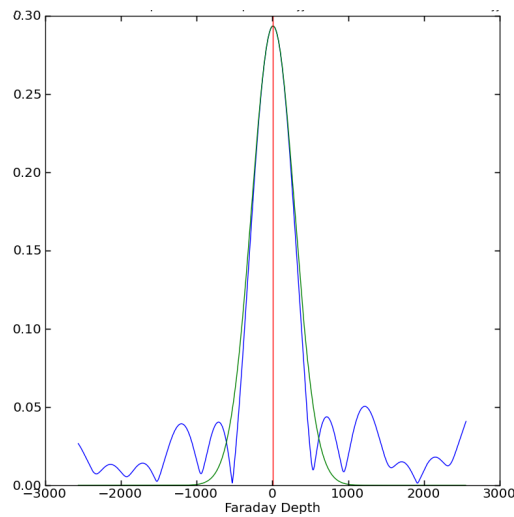


Figure 2: The typical Faraday spectrum of a compact source in the preliminary N1 data

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